

***A Science Review on Policy for
Augmentation and Supplementation
of Wild Steelhead Trout with
Hatchery Fish in British Columbia***



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**Contract Report
for B.C. Ministry of Natural Resources.**

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“A thing is right when it tends to preserve the integrity, stability, and beauty of the biotic community. It is wrong when it tends otherwise.” – Aldo Leopold, *A Sand County Almanac*.

This is a science perspective on policy issues related to the use of hatchery steelhead trout (*Oncorhynchus mykiss*) to augment (provide catch) or supplement (assist wild recovery) wild steelhead trout populations in British Columbia. The perspective is based largely on results of historic practice and use of hatchery steelhead in British Columbia, and recent scientific research and hatchery reforms in the Pacific Northwest of the United States. Evidence and experience were garnered from work by Provincial steelhead trout scientists and in review and evaluation of proposals and reports of empirical observations of salmonid augmentation and supplementation in major projects and proposals on the Columbia River, and recent fisheries science publications.

The perspective is structured as follows. The focus of the report is provided, followed by a brief description of the current policy and its management context. Based on west coast experience, I then summarize genetic and ecological risks associated with hatchery fish interactions with wild fish, and present three current computer simulation studies that have attempted to address hatchery-wild interactions. Empirical studies and supplementation experiments are then reviewed, followed by a summary of the recruitment effects, and overall conclusions, indicating that after review of the recent science, the Province of B.C. Stream Classification Policy appears appropriate as it stands.

Focus of the report

The Fish and Wildlife Branch of the Ministry of Natural Resource Operations is developing a provincial steelhead management plan to establish a unified approach for the management of this species across B.C. One aspect of this initiative is to review and update the Steelhead Stream Classification Policy (Appendix 1). The purpose of this contract is to ensure that management decisions on the use of hatchery fish under the Policy are supported by the most current science and can be consistently applied under all likely conditions ranging from conservation to recreational interests. To this end, the Ministry retained the Contractor to assist in this task, including:

- (a) Review all relevant published and grey literature for BC and neighbouring western states (Washington, Oregon, California) that evaluates the costs and benefits of hatchery production to augment (for fisheries) or supplement (for conservation rebuilding) wild populations of anadromous salmonids (emphasis on steelhead trout).
- (b) Using the Ministry policy (Appendix 1) for reference, produce a concise report to specifically address, at a minimum, the following questions:
 1. How are supplementation and augmentation differentiated?
 - The Contractor will provide a clear, concise definition of both terms as they apply to the use of hatcheries in steelhead trout management.
 2. Under what, if any, circumstances should the Ministry consider initiating/maintaining a supplementation program to assist in rebuilding a depleted steelhead trout stock?
 - Considerations will include stock status (Extreme Conservation Concern, Conservation Concern), as well as WILD and HATCHERY AUGMENTED classifications, as defined in the Policy. The Contractor should support all arguments with the most current research findings.
 3. What conclusions can be made regarding the degree to which supplementation efforts to date have been successful in BC, in the US?

- Relevant research on salmon and steelhead supplementation from the Pacific Northwest will be considered.
4. Should the Ministry ever consider augmenting a steelhead population which is currently designated as a WILD steelhead stream?
 - The Contractor will discuss the risks of augmentation to wild populations most current literature, especially BC-origin, where available and relevant.
 5. How should an augmentation program be adjusted according to stock status for HATCHERY AUGMENTED streams?
 6. What recent US research findings are applicable to policy development for steelhead hatchery use in BC?
 - Discuss the relevance of recent results of research on wild/hatchery interactions related to augmentation and supplementation in the western US to the steelhead trout policies within BC

Current policy, basis, and management context

The current Stream Classification System for British Columbia (Appendix 1) defines the current policy on use of hatchery fish. The process entails a stream-by-stream definition of stock status based on three distinct management zones (Fig. 1) defined by recruitment and management prescriptions (Johnston et al. 2002) that include augmentation with hatchery fish within the upper or routine management zone of relatively high abundance of wild fish.

At present, approximately 426,000 hatchery steelhead smolts are released into 14 steelhead trout streams to augment the catch (Table 1) in British Columbia. Anglers may retain hatchery steelhead but all wild steelhead trout must be released.

Guidelines, developed early in the inception (~1970) of B.C.'s fish culture program, have been established for steelhead fish culture and release to maximize the recreational fishery and minimize the impacts to wild stocks:

- All hatchery smolts are marked;
- Utilization of wild, unmarked broodstock collected during the entire breadth of the run;
- Hatchery smolt releases are directed to the lower reaches of the river system;
- There is no transport or release of steelhead without approval of the Federal-Provincial Introductions and Transfers committee; and,
- Programs are sized not to exceed a 1:1 wild to hatchery ratio in the catch.

These guidelines have been followed, to the best of my knowledge, with few exceptions. In several (4) hatchery streams, hatchery brood stock have been utilized when wild brood were rare or absent. Two of these are systems (Campbell River in Region 1, Stave River in Region 2) where a wild stock has been extirpated, or depleted and otherwise reduced to the point that recovery is not considered possible. The two others (Chehalis and Seymour river summer-runs) appear as exceptions to policy, or prior to subsequent adjustment to wild abundance (and thus out of the Routine Management zone). Estimation of the latter is difficult and rarely conducted, which further poses doubt on the ability to consistently achieve the 1:1 ratio of wild to hatchery fish in the catch.

Table 1. Releases of hatchery steelhead trout smolts within British Columbia in 2010. All but Stave River are smolt releases only. H= hatchery broodstock, W = wild broodstock. All fish are marled with an adipose (AD) fin clip, some also have clips to right maxillary (RM), or left ventral (LV). For a map and definition of regions please see <http://www.env.gov.bc.ca/main/regions.html>. DFO= Department of Fisheries and Oceans, FFSBC = Freshwater Fisheries Society of B.C.

Region	System	Hatchery	Agency	Location of Broodfish Origin	Origin	Number released	Mark	Average wt (g)
1	Campbell River	Quatse River	public	Tsitika	H	25,263	AD	64.3
1	Cluxewe River	Quatse River	public	Cluxewe	W	20,798	AD	69.1
1	Quatse River	Quatse River	public	Quatse	W	17,160	AD	82.4
1	Somass River - summer and winter	Robertson Creek	DFO	Stamp/ Somass	W	96,553	AD	69.9
2	Alouette River	Fraser Valley	FFSBC	South Alouette	W	24,652	AD	62.5
2	Campbell River	Little Campbell River	DFO	Little Campbell	W	11,665	AD	82.6
2	Chehalis River -summer	Chehalis River	DFO	Chehalis	H	11,739	AD, RM	80.8
2	Chehalis River -winter	Chehalis River	DFO	Chehalis	W	17,636	AD	78.9
2	Chilliwack/ Vedder River	Chilliwack River	DFO	Vedder - Chilliwack	W	119,289	AD	81.5
2	Seymour River	Seymour River	Public	Seymour	H	1,371	AD,LV	67.5
2	Stave River	Inch Creek	DFO	Vedder/ Stave	H	19,998	AD	85.7
2	Stave River	Fraser Valley	FFSBC	Vedder/ Stave	H	3,073	AD, RM	85.8
2	Stave River (Fingerling)	Fraser Valley	FFSBC	Vedder/ Stave	H	3,073	AD, RM	2
6	Kitimat River	Kitimat River	DFO	Kitimat	W	53,791	AD	35.2
						426,061		

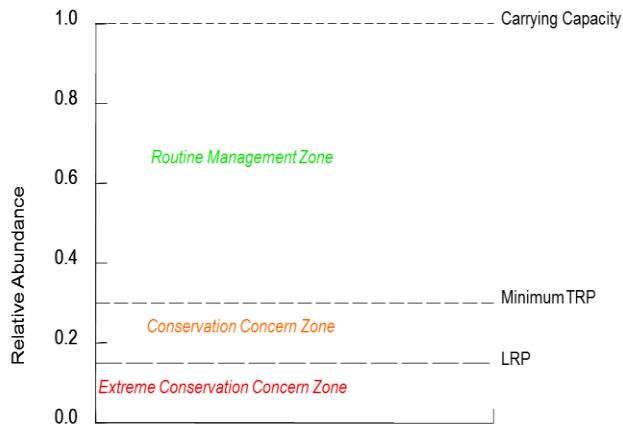


Fig. 1. A management framework that uses reference points defined in terms of steelhead abundance results in three distinct management zones with different management objectives and actions. The carrying capacity is the asymptotic maximum recruitment. TRP and LRP are target and limit reference points. The locations of the minimum TRP and LRP here are for illustrative purposes only (from Johnston et al. 2002b).

Interactions between hatchery and wild steelhead.

Conceptually, interactions between hatchery and wild steelhead trout and their consequences for sustainability of natural populations require consideration of ecological and genetic interactions. Much of the attention on this issue has focused on the latter, and in particular, questions of reduced effective population size, in-breeding and out-breeding depression, genetic drift resulting in loss of genetic variation, and domestication and selection for traits more conducive to survival in the hatchery versus the wild. Ecological risks can include competition, predation, behavioural interactions, residualism, and issues associated with mixed-stock fisheries. The combination of genetic (e.g. reduced fitness) and ecological (e.g. density dependence) impacts can significantly reduce productivity in the natural population.

Experiments at the watershed scale to evaluate these issues are rare and complex, but some recent studies in B.C. and the neighbouring western states are completed or ongoing. However, recently developed computer simulation studies facilitate an opportunity for managers and stakeholders to better understand the trade-offs associated with levels of hatchery production, harvest, natural production and population status. These models are useful as a planning, predictive, and analytical tool towards evaluation of risks and benefits, and the development of experiments, and are thus briefly described here, following summaries of reviews of genetic and ecological impacts. I conclude with evidence from empirical studies, and an overall summary and recommendations.

Genetic risks:

Recent work on genetic risks includes ground-breaking projects on the Hood River, Oregon, in the Columbia River basin. In a proposal to the Northwest Power and Conservation Council¹, Blouin articulated the case, mainly from landmark earlier studies and his own research, that hatchery fish have lower fitness than wild fish. He states: “Genetic change via captive breeding has been documented in a wide variety of taxa, and it poses a serious problem for ex-situ conservation (captive breeding and release) programs (Frankham, 2008; Montgomery et al., 2010). This phenomenon is particularly well documented in salmonid fish. Traditional hatchery stocks (those propagated for many generations using returning hatchery fish as parents) are genetically different from wild populations for a wide variety of adult and juvenile traits (reviewed in Fleming and Petersson, 2001, and in Bilby et al., 2005). Fish from traditional hatcheries usually have much lower fitness than wild fish when they breed in the wild (often < 10% that of wild fish: reviewed in Berejikian and Ford, 2004, Araki et al., 2009, and Recovery Implementation Science Team, 2009).” Domestic brood stocks are largely phased out in Oregon and Washington for this reason (see HSRG discussion, below).

Blouin further adds: “What had not been appreciated until recently is how rapidly this fitness decline occurs. For example, hatchery-produced Chinook salmon juveniles were less aggressive and more vulnerable to predators than wild juveniles after only a single generation in a state-of-the-art hatchery (Fritts et al., 2007; Pearsons et al., 2007). Here the juveniles were raised in identical environments - they differed only in parentage. Reisenbichler and McIntyre (1977) made all possible crosses among wild and hatchery steelhead trout (HxH, HxW, WxH and WxW), where the hatchery fish had been derived from the same wild population only two generations earlier. Offspring were released into fenced off streams as eyed-embryos or fry, and recaptured 12 months later (parentage assigned using allozymes). Juveniles produced from hatchery parents showed approximately 85-90% the survival of juveniles produced using wild parents, while hybrids were intermediate (Reisenbichler and McIntyre, 1977; Reisenbichler and Rubin, 1999). When the same families were reared in a hatchery pond, the HxH offspring survived and grew best.”

“Consistent with the above results, three studies have now shown first-generation hatchery fish to have significantly lower lifetime reproductive success than wild fish (from two populations of steelhead and a population of coho). E. Berntson and colleagues found the relative reproductive success (RRS) of first-generation steelhead in Little Sheep Creek, Oregon, to be consistently between 0.3 and 0.6 that of wild fish in six run years (E. Berntson, in preparation). In a similar study, V. Theriault and colleagues studied three run years of coho in Calapooya creek, a tributary of the Umpqua River. The RRS for first-generation hatchery fish averaged 0.56 to 0.77 that of wild fish (Theriault et al., unpub. data). We found similar results for winter-run steelhead in the Hood River...”

¹ [Proposal RMECAT-00112 - Evaluate the Relative Reproductive Success of Hatchery-Origin and Wild-Origin Steelhead Spawning Naturally in the Hood River. Project Number: 2003-054-0 6/7/2010 by Michael Blouin (blouinm@science.oregonstate.edu <http://www.cbfish.org/Proposal.mvc/Summary/125>)]

He further summarized his work as follows: “The older hatchery stocks of steelhead in the Hood River had 10-30% the fitness of wild fish when both spawn in the wild (Araki et al., 2007a). First generation hatchery fish (i.e. fish created using wild parents as broodstock) have about 15% lower fitness than wild fish (Araki et al., 2007b). A comparison between first and second-generation fish raised side-by-side in the same hatchery showed that each generation spent in the hatchery substantially reduced the performance in the wild of the hatchery fish (Araki et al., 2007b). Because both types of fish experienced identical environments, and because the reciprocal crosses showed no evidence of maternal effects, the difference is almost certainly genetic. We estimated an initial average decline in fitness of 37.5% per generation of hatchery rearing”.

“Data such as these are disturbing because hatchery and wild fish are allowed to mix freely in many rivers. Furthermore, many hatcheries have adopted the mission of supplementation. The assumption had been that using local, wild-born fish as parents every year would circumvent the domestication effects that are so apparent in multi-generation stocks. However, if that assumption is not true, then supplementation efforts may actually drag down the fitness of the wild stocks they are meant to support (Ford, 2002; Goodman, 2005; Lynch and O’Hely 2001). Last year we analyzed the fitness of wild-born fish that differed in parentage, and found that wild-born offspring of naturally occurring HxH, WxH and WxW crosses also differed substantially in fitness (Araki et al., 2009). Because the fish of different parentages presumably experienced identical environments (this time in the wild), the difference between them is probably genetically based. Thus, these first-generation fish probably are dragging down the fitness of the wild population, although the extent of the effect still needs to be estimated accurately.” He then develops a proposal for further research, including a search for causes of this decline.

Araki et al. (2009) summarized their findings on review of relative fitness of hatchery-reared salmonids in the wild and concluded that hatchery fish have lower fitness in natural environments than wild fish in general. Nonlocal hatchery stocks consistently reproduced very poorly in the wild, as was also demonstrated by Araki et al. (2007a,b) for Hood River steelhead; hatchery stocks that use wild, local fish for captive propagation generally perform better than nonlocal stocks, but often worse than wild fish. They added that if selection acts on multiple traits throughout the life cycle, rapid fitness declines are plausible.

Summary of potential genetic risks:

- reduced effective population size,
- inbreeding depression,
- outbreeding depression
- Domestication selection or artificial selection of broodstock
- Loss of genetic variation (drift and selection)
- Loss of local adaptation due to homogenization from increased straying rate associated with hatchery fish - strays intermingle, can outnumber and spawn with wild

Ecological risks:

The sudden addition of large numbers of hatchery fish, typically more and larger in size than wild fish, can have several ecological impacts. In a recent well-written and thorough review on hatchery releases from US Federal and State facilities, Kostow (2009) provided numerous insights on ecological impacts. She listed 5 key contributing factors to ecological risk induced by: relative abundance of hatchery and wild fish; increases to density-dependent mortality, residual hatchery fish, physical advantages of hatchery fish, and life history characteristics (e.g., aggression, run-timing, spawn timing) that increase risk. In summary, 12 management strategies were recommended to mitigate ecological risks (text includes explanation of each):

1. Operate hatchery programs within an integrated management context,
2. Only implement hatchery programs that provide a benefit,
3. Reduce the number of hatchery fish that are released,
4. Scale hatchery programs to fit carrying capacity,
5. Limit the total number of hatchery fish that are released at the regional scale,
6. Only release juveniles that are actively smolting and will promptly out-migrate,
7. Release smaller hatchery fish, provided they are smolting,
8. Use acclimation ponds and volitional releases,
9. Locate large releases of hatchery fish away from important natural production areas,
10. Time hatchery releases to minimize ecological risk,
11. Restrict the number of hatchery adults allowed in natural production areas,
12. Mark 100% of the hatchery fish and monitor the effects of hatchery programs.

Viewing British Columbia's hatchery steelhead program in the context of these recommendations, it appears that there are weaknesses in several areas, but especially numbers 3, 4, 6, 7, 8, 10, 11, and for 12 (B.C. fish are marked, but lack sufficient monitoring). Many of these same issues of ecological risk were discussed by Ward (2006 MS) in reference to a short-term recovery attempt due to a catastrophic spill event in the Cheakamus River.

Summary of potential ecological risks:

- density dependence
- increased competition, predation
- residualism
- prey and predators
- predator attraction
- mixed-stock fisheries effects (non-target selection, overharvest)
- spawners removed from wild for brood
- disease

Density dependence, either in the numbers of spawning adults, juveniles, or smolts, may be the key issue in some hatchery introductions. Kostow and Zhou (2006) reported an effect of a hatchery program for summer steelhead on the productivity of a wild winter steelhead population in the Clackamas River, Oregon. When high numbers of hatchery summer steelhead adults were present, the production of wild winter steelhead smolts and adults was significantly decreased, based on recruitment analyses. They concluded that over the duration of the hatchery program, the number of hatchery steelhead in the basin regularly caused the total number of steelhead to exceed carrying capacity, triggering density-dependent mechanisms. The number of smolts and adults in the wild winter steelhead population declined until critically low levels were reached in the 1990s. Hatchery fish were removed from the system in 2000, and early results indicated that the declining trends have reversed.

Simulation studies

SHWIM (Steelhead Hatchery-Wild Interactions Model):

Korman and Ward (2007 MS) simulated demographic, quantitative genetic, and harvest dynamics to evaluate alternate broodstock and restoration strategies for recovery of a steelhead trout populations in B.C., the Seymour River. The steelhead hatchery-wild interaction model followed Ford (2002) with modifications that included freshwater and marine life stages, a wider range of hatchery broodstock policies, and catch and effort dynamics of the recreational fishery, including parameterization with real data from the Keogh River for improved application. They compared, using simulation modeling, the relative benefits of no broodstock, wild-origin spawners, hatchery-origin spawners, or combinations, and improvements in freshwater productivity (smolts/spawner) through habitat restoration under different marine survival scenarios, i.e., above, at, and below recruitment replacement.

Fitness impacts were most severe using hatchery-only broodstock, especially when wild stock productivity was very low. However, a halt of hatchery operations resulted in faster population declines when wild productivity was below replacement level. A wild-origin broodstock policy resulted in the least genetic impact but was not sustainable under low freshwater productivity/marine survival scenarios. A combined strategy with wild broodstock when sufficient wild fish were available, supplemented with hatchery-origin fish (originally from wild) during periods of low productivity performed best in terms of compromised fitness and population sustainability. Likewise, the model suggested that benefits of habitat restoration alone were insufficient to reverse population decline during sustained periods of extreme low marine survival. In such circumstances, the use of mixed-origin broodstock combined with habitat restoration was an alternative for sustaining steelhead populations at risk of extirpation. The model requires further testing on other steelhead hatchery systems, field verification, and update based on recent science, but was useful to explore alternative policies.

AHA:

The All H Analyzer (AHA) is a Microsoft Excel-based model to evaluate salmon stocks in the context of the three “H’s” that affect their health and abundance—Habitat, Harvest and Hatcheries. The model was created in 2004 by the Hatchery Scientific Review Group (HSRG), Washington State Department of Fish and Wildlife (WDFW) and Northwest Indian Fisheries Commission (NWIFC) for use in a series of regional, technical workshops held during the

summer of 2004. Long Live the Kings assisted in the preparation of this users guide. As the User's Guide describes, the AHA model allows users to input data reflecting current habitat productivity/capacity, harvest rates, and hatchery operations. The model then predicts what should result from that set of factors, both in terms of the number of fish returning to the habitat, harvest and hatchery, and the amount of influence the natural environment will have on the composite, integrated hatchery/natural population. The model also allows the user to explore how these results will change in the short- and long-terms if habitat, harvest and/or hatchery parameters are changed. In this way, the model lets the user confirm current conditions (including how well or poorly the current hatchery component of the population is integrated with the natural component), describe a vision for the long-term future of the population (including habitat conditions, harvest rates and hatchery programs), and develop one or more short-term scenarios for achieving or approaching that vision. The model has received extensive review, including that from the Northwest Power and Conservation Council's Independent Scientific Review Panel (ISRP 2005-5): <http://www.nwcouncil.org/library/isrp/isrp2005-5.htm>

An example of its application on the Snohomish River Chinook salmon is available:

http://www.co.snohomish.wa.us/documents/Departments/Public_Works/surfacewatermanagement/2nd/Library/final_report_wria_7_all-h_analyzer.pdf. All hatchery operations in the Columbia River basin, Puget Sound, coastal Washington, and California, have subsequently come under review by the HSRG using AHA, which then lead to numerous recommendations for reforms, many of which are aimed at reducing the impact of hatchery fish on wild fish – see www.hatcheryreform.us.

Proposed hatchery development for the Chief Joseph Hatchery Program provides another example of application of recent science and models to hatchery development. The Colville Tribes in Washington State have developed a two part monitoring and evaluation plan (one for summer/fall and one for spring Chinook salmon) to manage the Chief Joseph Hatchery Program that is consistent with the Master Plan and Fish and Wildlife Program adaptive management. The essential features of the experimental plans are decision frameworks for the scale of artificial production based on the abundance of natural-origin summer/fall Chinook (or spring Chinook for the reintroduction program) with constraints (via selective harvest and trapping) on the number/proportion of hatchery-origin salmon that can mix with natural-origin fish on the spawning grounds. This framework, reviewed by ISRP, was based on AHA modeling (Möbrand et al. 2006) and is consistent with best management practices for artificial production as developed by the Hatchery Scientific Review Group (HSRG 2006) that have contemplated guidelines for co-managing natural and hatchery populations for harvest and conservation. <http://www.nwcouncil.org/library/isrp/isrp2010-1.pdf>

The Shiraz model: a tool for incorporating anthropogenic effects and fish–habitat relationships in conservation planning.

Scheuerell et al. (2006) outlined a framework for incorporating detailed information on density-dependent population growth, habitat attributes, hatchery operations, and harvest management into conservation planning in a time-varying, spatially explicit manner. This model utilized a multi-stage Beverton-Holt life history approach and incorporated habitat, hatchery, and harvest information to assess abundance, productivity, spatial structure, and life-history diversity. This, and/or the simulation models above provide opportunity to explore options and scenarios prior to

embarking on expensive hatchery operations, as done by these authors for two Chinook populations of the Snohomish River, WA.

Empirical studies

Smith and Ward (2000) reviewed the trends in abundance of steelhead trout in B.C. coastal streams. They found that rates of decline in angler catch were evident throughout the 1990s, yet rates of decline were greater in streams with wild and hatchery fish than in wild-only streams (Fig. 9, Smith and Ward 2000).

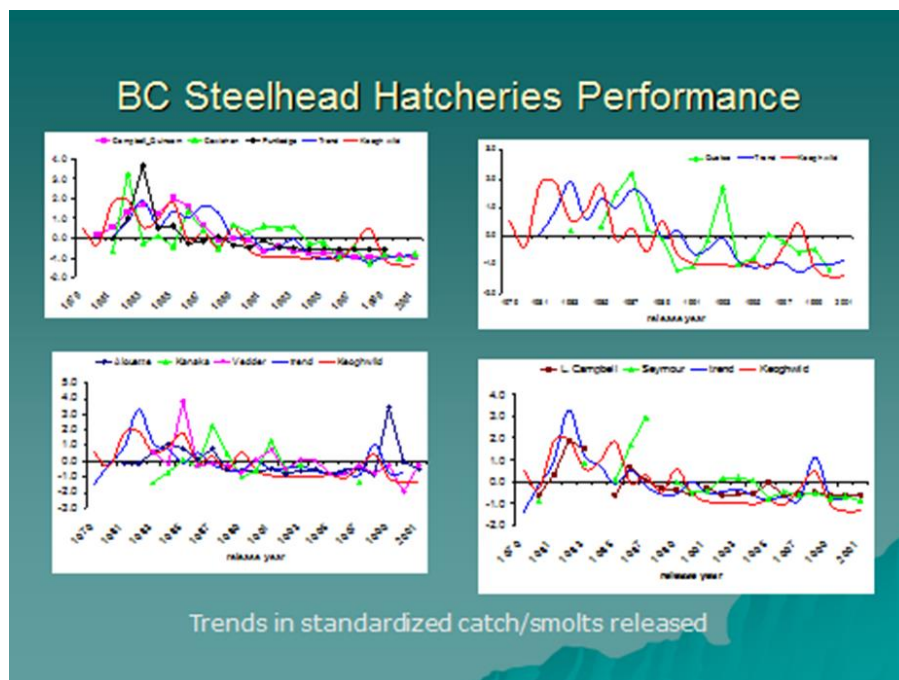


Figure 2. Trends in standardized catch per smolt released in southern B.C.'s steelhead trout hatchery streams. Modified from Smith and Ward (2000).

Recent investigations on genetic effects utilizing archived scale samples (e.g., Heggenes et al. 2006, Gow et al. 2011 in press) concluded that genetic variation, as measured by several neutral genetic markers, did not vary over time, suggesting that the broodstock numbers were probably adequate to prevent shifts in neutral genetic diversity over time. Gow et al. (2011) detected no changes in estimates of effective population size, genetic variation or temporal genetic structure within any population, nor of altered genetic structure among 5 populations of steelhead using similar methods as Heggene set al. (2006). While reassuring that catch augmentation can be provided using wild broodfish without impact to wild genetics, these papers did not consider

changes in fitness or adaptive traits. In fact, it may be that the B.C. release guidelines (policy) serve to segregate wild and hatchery fish on the spawning grounds. Hatchery fish are released and tend to return and spawn in lower reaches of watersheds and thus may experience little or no reproductive success, whereas refugia are provided to wild spawners in the upper reaches, where their reproductive success may be higher (e.g., Nelson et al. 2005). They also noted that although no genetic changes were detected, ecological effects of hatchery programs still may influence wild population productivity and abundance. These studies could not address the issue of ecological impacts, best assessed as a function of smolt and adult recruits per spawner in a control and reference design.

Summary of potential areas of difference between hatchery and wild fish from empirical evidence:

Biology and Life History

- lower reproductive success in the wild
- reduced mating success
- younger age
- sex ratio differences
- residualism
- lower survival to fry, smolts, adults
- reduced fitness of wild when interbreeding
- disease

Morphology:

- lower size
- body shape
- fin shape
- fecundity
- internal organ size

Behaviour:

- swimming performance
 - agonistic
 - predation performance
 - predator avoidance
-

Buhle et al. (2009) examined 15 populations of coho salmon along coastal Oregon where there was a large-scale reduction in hatchery stocking. They concluded that negative effects from hatcheries were two of the four critical factors influencing wild salmon productivity in this study, including a demonstrated decrease in wild salmon productivity as hatchery juveniles increased in the system. Wild populations of coho improved when fewer hatchery fish were present. The strongest negative effects of hatcheries were associated with hatchery-reared adults breeding in

the wild, precisely the pathway that might have been expected to contribute most to population rebuilding. Interactions with environmental influences was also important, and particularly the broad-scale declines in ocean productivity, and other ecological drivers. They suggested that, for example, releasing large numbers of captive-reared juveniles could pose a greater risk to wild populations during periods of poor ocean survival.

In contrast, Sharma et al. (2006) concluded that a supplementation (hatchery) program, in this case following new and innovative operational protocols, can produce smolts that have nearly the same survival rate to adults as that of wild smolts and can result in more adult coho returning to the Clearwater basin. This benefit appeared possible without short-term adverse impacts to either intrinsic productivity or the number of naturally produced smolts. However, the long-term outlook is uncertain and cannot be inferred from the data generated during the first 10 years of this program.

A thorough and lengthy review of the impacts of conservation and fishery enhancement hatcheries on wild populations of salmon was provided by Naish et al. (2008), including historical, political, and science aspects. They note that while hatcheries may have a role in preserving critically endangered wild stocks (e.g., Snake River sockeye salmon captive propagation), it was not clear that hatcheries can support conservation and fishery goals, and that experimentation was necessary. They further emphasized the need for active debate about the roles of hatcheries in today's society. Hatcheries have failed to stem the decline of wild populations, and may have exacerbated that effort in some cases. They list, with references, several biological problem areas, including: changes in genetic diversity, risk of transmission of disease to wild, exceeding the carrying capacity of streams and oceans, and overharvest of wild stocks in mixed-stock fisheries, yet also acknowledge the complexities induced by societal desires and demands.

Supplementation Experiments

The B.C. supplementation experience: The Living Gene Bank Project:

B.C.'s Living Gene Bank (LGB) project was an unsuccessful attempt at increasing wild smolt yield using hatchery releases during an ongoing period of poor return rates of wild adult spawners. The experimental program was established in 1998 in response to increasing risks of extinction of most steelhead trout populations on the east coast of Vancouver Island. Wild juvenile fish (smolts) representative of the genetic diversity of the wild population were randomly selected and reared to maturity, spawned, and their progeny reared then released into the natal river as smolts. Three Vancouver Island populations (Keogh, Little Qualicum, and Quinsam Rivers) were chosen and the program was conducted on a trial basis to see if the objectives of refuge and amplification within the hatchery, maintenance of genetic diversity, and increase in wild numbers could be achieved (Amman et al. 2004).

The Keogh River was the only site where smolt yield and returns of wild and LGB steelhead were closely monitored and reported (e.g., McCubbing and Ward 2006). LGB smolt releases and resultant additional spawners (circa 200-400 fish) did not boost wild smolt yield (post-LGB spawning) nor subsequent wild adult returns. There has been a persistent declining trend in adult spawner abundance; returns in 2009 were the lowest recorded during the last decade. Thus, the

persistent low marine survivals combined with the low smolt output (possibly further reduced by the presence of hatchery fish) from 2004 to 2009 (500 to 3,800 smolts, or 2 to 10-fold lower than previous capacity records) remain a great cause for concern. Population viability modeling suggests that the population may be unsustainable when smolt yield is less than 1500 fish unless marine survival is greater than 5% (Ward 2000); it is less at present. Parentage analyses were not completed due to lack of support, but it was clear that very little positive contribution to wild smolt yield was evident, if any. Indeed, several ecological interactions (e.g., competition for space, predation by residualized fish) as well as lowered relative reproductive success of LGB spawners and wild-X-LGB spawners may have contributed to a lack of response in smolt yield.

The Columbia River Basin supplementation experience:

The U.S. fish and wildlife agencies have been directed by Congress to conduct reviews of hatchery programs with the purpose of modifying programs to ensure protection of natural populations and operating the hatcheries for harvest. These reviews have been conducted through a Hatchery Scientific Review Group (HSRG). To date, program reviews in Puget Sound and the Columbia River have been completed, and programs in California are currently under review. These intensive hatchery reviews include analyses and computer simulation studies (AHA) for each major operation. Revised policies are under discussion through the Endangered Species Act. Most reforms will involve reduced hatchery production.

Recommendations for broad-scale monitoring to evaluate the effects of hatchery supplementation on the fitness of natural salmon and steelhead populations have been developed for the Columbia Basin by the Ad Hoc Supplementation Monitoring and Evaluation Workgroup, an interagency workgroup, with the encouragement of the ISRP (Galbreath et al. 2008). This approach involves, 1) an investigation of the long-term trends in the abundance and productivity of supplemented populations relative to un-supplemented populations, 2) conducting a series of relative reproductive success studies to quantify short-term impacts, and 3) development of a request for proposals to fund several intensive small-scale studies designed to elucidate various biological mechanisms by which introduction of hatchery-produced fish may influence natural population productivity. The work is ongoing; recent results are discussed herein, below.

Supplementation remains experimental, and there is not sufficient weight of evidence to conclude that there is a benefit to natural populations. Further, there is evidence that in some rivers, natural population performance has been depressed by the presence of hatchery supplementation fish. The ISRP (2011) concluded from the recent review of hatchery programs on the lower Snake River that the BACI (Before-and-After-Control-Impact) analysis from the Imnaha River and inspection of data and trends from other programs with a supplementation design indicate that these programs are not yielding an increase in natural-origin adults over unsupplemented reference locations. There is an absence of support for the argument that these programs provide conservation by reducing demographic risk. Furthermore, HSRG has argued, and the ISRP concurs, that scientific foundations from population genetics and demography demonstrate that integrated harvest programs require a natural population that is replacing itself, a program where the size of the natural population exceeds the size of the hatchery population, and where gene flow must be greatest from the natural population to the hatchery population (ISRP 2011). Hatchery releases and evaluations on the Imnaha River, as part of the Lower

Snake River Compensation Program, serve to provide example of the appropriate parameters and endpoints or response variables to evaluate trends following supplementation.

Not all supplementation attempts have resulted in negative impacts to wild populations. When underlying causes for decline were addressed, via habitat modifications, wild populations rebounded quickly when supplemented with hatchery stock derived from wild brood (they may have responded quickly regardless). The example in the Columbia River basin comes from the Umatilla River, near Pendleton (Schwartz et al. 2006). It is likely that supplementation and habitat restoration effects were confounded. The Umatilla has had substantial alteration of the hydrograph (added flow pumped from the Columbia River). The extent to which the modest benefits observed are due to hydrograph and habitat restoration versus supplementation is not clear.

Recruitment effect:

Recently, Chilcote et al. (2011) found a negative relationship among the reproductive performance in natural, anadromous populations of steelhead trout, coho salmon (*O. kisutch*), and Chinook salmon (*O. tshawytscha*), and the proportion of hatchery fish in the spawning population. They used intrinsic productivity as estimated from fitting a variety of recruitment models to abundance data for each population as their indicator of reproductive performance, and found that across a broad geographical range (Pacific Northwest) and three different species, the proportion of hatchery fish was a population characteristic that was negatively associated with reproductive performance in wild fish, in both integrated and segregated situations from 89 populations. Results suggested that the net reproductive performance of the wild population will decline under all hatchery supplementation scenarios. They further conclude that “bringing wild salmonids into a hatchery environment to prevent the extinction of a genetic lineage should only be considered when there is very little likelihood that the population will sustain itself in the wild”, and that “under most circumstances the long-term conservation of wild populations is best served by the implementation of measures that minimize the interactions between wild and hatchery fish”.

Costs and benefits:

Summer steelhead smolts released at the Irrigon hatchery cost \$1.30 per release, according to an economic analysis of the spending on overall artificial production projects on the Columbia River, which accounted for \$312 million of the Northwest Power Planning Council’s fish and wildlife program budget during 1978-19991 (IEAB 2002). The cost per fish harvested is approximately \$1,000 – cost per surviving adult fish was found, as expected, to be highly variable among hatchery programs. Cost effectiveness was not, nor could not be included. The economic analysis did not appear to include amortized hatchery construction and maintenance costs nor amortized benefits or a “willingness to pay” approach in the evaluation. Ecological risks and costs were not calculated or included. Simulation studies of costs and benefits for various hatchery scenarios at variable wild abundance appear lacking, and should be conducted.

Summary and conclusions.

The following issues/questions were addressed in the review:

1. How are supplementation and augmentation differentiated?

Augmentation refers to the use of hatchery fish to add to the abundance of the catch, and is typically used as mitigation for lost production related to an anthropogenic cause. In B.C.'s case, augmentation is used to augment the catch of steelhead trout in recreational fisheries where wild fish may not be retained. There is no intention to increase natural production; in fact, many programs are designed to minimize potential wild/hatchery interactions particularly on spawning grounds. Supplementation of the wild stock involves the release of hatchery fish to assist in the re-building of the stock. The Columbia Basin's Regional Assessment of Supplementation Project report (RASP 1992) provides a useful working definition for supplementation: Supplementation is the use of artificial propagation in an attempt to maintain or increase natural production, while maintaining the long-term fitness of the target population and keeping the ecological and genetic impacts on non-target populations within specified biological limits.

2. Under what, if any, circumstances should the Ministry consider initiating/maintaining a supplementation program to assist in rebuilding a depleted steelhead trout stock?

This consideration should occur in very few if any circumstances, and only as a last resort, i.e., only in those circumstances where the trend in abundance suggests the population could become extirpated within one or two generations and there is reasonable belief that a hatchery program could be initiated that had a hatchery steelhead replacement rate > 1.0 (i.e., hatchery fish are returning in numbers that are greater than the number of broodstock). There is little to no evidence that supplementation for salmonids can recover wild populations. However, if the limiting factors associated with the population decline have been addressed, re-introductions may be successful at re-establishing populations, which may re-adapt over time.

3. What conclusions can be made regarding the degree to which supplementation efforts to date have been successful in BC, in the US?

There has been no success in B.C., but $n=1$, i.e., only results from the Keogh River LGB experiment are relevant, where no increase in wild smolt yield was evident. There have been mixed results for Chinook and coho salmon and steelhead trout elsewhere, but mainly negative, as reviewed above.

4. Should the Ministry ever consider augmenting a steelhead population which is currently designated as a WILD steelhead stream?

Yes, if and only if the wild stock is in abundance (RMZ) and can thus withstand the genetic and ecological impacts that may result in reduced productivity – see Chilcote (2011). A reasonable and responsible approach would include the guidelines of Lorenzo et al. (2010).

5. How should an augmentation program be adjusted according to stock status for HATCHERY AUGMENTED streams?

The wild stock must be within the Routine Management Zone, and policy guidelines followed.

6. What recent US research findings are applicable to policy development for steelhead hatchery use in BC?

The text above provides evidence from genetic, ecological, computer simulations, and empirical studies that were applicable to the B.C. Stream Classification policy and use of hatchery fish.

Overall Conclusions

In conclusion, while policy related to hatchery steelhead trout in British Columbia requires regular review and adaptation to recent science, based on this review, the current policy requires little if any change to match current science. Use of hatchery trout to rebuild wild steelhead populations remains highly questionable and is not recommended until research proves otherwise. Evidence to date suggests this has not been demonstrated. As a method to maintain genetic structure of severely depleted and endangered populations, hatcheries may play some role, as a last resort, as identified in the policy, to avoid extinction. Such cases will be entirely dependent on hatcheries for existence.

There is no empirical evidence that hatchery operations have preserved populations that experienced catastrophic declines in abundance. Several populations of Chinook salmon in the Columbia River basin went into captive rearing programs in the mid-1990s because less than 10 adults returned to spawning streams. The populations that had captive-rearing programs have generally fared no better than populations that were not involved in such intensive management. For example, in the Grande Ronde River basin in Oregon, the Lostine River, Catherine Creek, and upper mainstem Grande Ronde, were brought under captive rearing programs, whereas the Minam and Wenaha rivers were not. The Minam and Wenaha rivers fared no worse (perhaps better) than the streams where captive rearing technologies were employed (ISRP 2011). Snake River sockeye salmon and Sacramento winter run Chinook salmon have also been brought under captive rearing. It is not entirely clear in these cases if extirpation would have taken place. For example, there are residual Snake River sockeye (kokanee) in Redfish Lake, and smolt emigration was taking place annually, even when no anadromous adults were returning. Rainbow trout may be similar. Most hatchery programs are capable of developing self-sustaining broodstocks, and on that basis it could be argued that these programs could avert extirpation of a genetic lineage that has no substitute. If the program halted, the stock would likely fail.

Augmentation of the recreational harvest of steelhead is best only considered when the wild population is healthy (i.e., in the Routine Management zone) and capable of withstanding the potential impact or decline in relative reproductive success and ecological interactions that are likely to result. An ability to judge the potential to withstand this impact and stock status is contingent upon adequate monitoring of the resource, including habitat capacity and productivity, the viability parameters of the wild steelhead population and recruitment. This level of monitoring is currently not well-supported. A review of that science within B.C. may be required, particularly if hatchery production were to expand.

A cautious, adaptive management approach is encouraged. In northern B.C. populations, productivity and capacity are limited by harsh environments, thus surplus production is low, i.e., little to none. Interceptions in mixed-stock fisheries add further stress that would very likely

only be exaggerated by the addition of hatchery stocks. Careful simulation modeling of these potential impacts should confirm this.

In southern B.C., extreme low smolt-to-adult return rates have been the norm for over two decades. Hatchery fish return at rates that are 2- to 3-times lower than wild fish (e.g., Ward and Slaney 1990). There is no indication that any of the hatchery streams have benefitted from an increase in wild adult abundance from the addition of hatchery fish in southern B.C. The reverse appears more likely. While the release of more hatchery fish will provide more catch, this must be weighed against the costs of removal of wild brood stock (which themselves are highly productive at low density) and the potential negative impacts from hatchery returns on wild spawners and recruits.

Any consideration of further hatchery development should weigh the ecological, genetic, and economic benefits and costs carefully. Models may assist a decision process, and an adaptive environmental experimental approach. All indications to date from results within B.C. and in nearby states provide generally negative, if not mixed results. A very cautious approach is recommended, and not without cost. Effort may be better placed at understanding why steelhead trout are not surviving their marine life stage at rates seen previously, the key limit to population abundance.

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Appendix 1. Province of B.C. Stream Classification Policy.

3-2-02.01

Steelhead Stream Classification

• Effective Date: December 13, 2005

This Policy Replaces:

None.

Staff, Organizations Directly Affected (including but not limited to):

Ministry of Water, Land and Air Protection Ministry of Sustainable Resource Management

Ministry of Agriculture, Food and Fisheries Freshwater Fisheries Society of British Columbia

Fisheries and Oceans Canada Contract/volunteer hatchery operators Angling and guiding

organizations First Nations.

POLICY STATEMENT

Purpose: The use of hatchery steelhead (*Oncorhynchus mykiss*) and/or retention of wild steelhead can provide angling benefits, but may also impose risks to wild stocks. The overall purpose of this policy is to manage the risks in order to maintain healthy, self-sustaining wild steelhead stocks.

It is the Policy of the Ministry:

1. That all streams containing steelhead will be classified as:

(a) wild; or

(b) hatchery-augmented.

2. Streams will be classified as wild unless specifically designated as hatchery-augmented.

3. That streams designated “wild” will be managed to maintain and protect the abundance, distribution and genetic diversity of indigenous steelhead stocks in the province while providing angling opportunities when stock abundance permits.

4. That streams designated “hatchery-augmented” will be managed to maintain or develop new angling opportunities while minimizing risks to wild indigenous steelhead.

5. In no cases will hatchery-augmentation be considered as a substitute for habitat protection and restoration.

Reasons for Policy

1. To maintain the genetic diversity, general health, and long-term viability of wild indigenous steelhead stocks.

2. To recognize the risks of hatchery augmentation and to acknowledge the lack of scientific evidence to support the use of traditional hatchery practices to recover “at-risk” steelhead stocks.

3. To allow for the maintenance and development new steelhead angling opportunities in the province in appropriate locations.

4. To provide standard designations to support development of consistent management plans for steelhead stocks in the province.

5. To ensure that decisions with respect to the use of hatchery-augmentation are science based and consistently applied throughout the province through a structured decision making process.

6. To facilitate understanding and support for steelhead conservation, management and recovery strategies.

Definitions:

“Wild” steelhead streams — streams in which steelhead stocks and steelhead angling opportunities are sustained only by naturally produced indigenous fish. The historic stocking of

hatchery fish does not preclude a wild designation if there is reasonable expectation that the indigenous stock remains intact or can be recovered.

"Hatchery-augmented" steelhead streams — streams in which marked artificially propagated steelhead are released for the purpose of creating angling opportunities. Propagated steelhead includes progeny resulting from projects where eggs are taken from adults, fertilized and incubated in a facility of any kind. They also include trapping fry, parr or smolts and raising them for subsequent release or use as captive brood stock.

"Viable wild stock" — for steelhead will be determined on a stream-by-stream basis using the best available science and stock and habitat information.

Wild stock status is expressed relative to the estimated existing capacity of each individual watershed to produce naturally spawning steelhead as follows:

"Routine Management Zone" (RMZ) — stocks at least 30% of habitat capacity;

"Conservation Concern Zone" (CC) — stocks are 10% to 30% of habitat capacity;

"Extreme Conservation Zone" (ECC) — stocks less than 10% of habitat capacity;

"Special Concern" (SC) — stocks are not well documented but believed to be very low.

3-2-02.01

Steelhead Stream Classification

- Effective Date: December 13, 2005

A.) Classification of Steelhead Streams

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The Ministry will classify provincial streams containing steelhead as "wild" or "hatchery-augmented" to meet steelhead conservation and management objectives.

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The objective is to maintain healthy, self-sustaining wild steelhead populations in British Columbia and, as such, the default classification will be "wild". Criteria for classifying a stream as "hatchery-augmented" include:

1.

Systems which have been historically augmented and where continued augmentation is not considered to pose a risk to extant wild stocks or;

2.

Systems where a wild stock has been depleted or otherwise impacted to the point that recovery is not considered possible or;

3.

Systems where a steelhead population never existed and potential impacts to other native species have been evaluated and are considered acceptable.

In all cases there must be a reasonable expectation of creating a viable angling opportunity in a cost-effective manner.

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Initial classifications and proposed subsequent changes will be developed regionally and must be reviewed technically by the Ministry's Anadromous Fisheries Committee before forwarding to the Environmental Stewardship Division Management Committee (DMC) for a final decision.

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Requested changes to the designation of a steelhead stream will be directed to the accountable regional manager who will prepare an evaluation that includes management objectives, potential consequences and their likelihood and, performance indicators.

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A schedule of hatchery-augmented streams will be established and updated as required.

B.) Management of Designated Steelhead Streams

The Ministry will manage designated provincial steelhead streams as follows:

"Wild" steelhead streams

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- No hatchery augmentation will be permitted.
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- Angling regulations are to be enacted that prohibit retention of wild steelhead to conserve wild fish, provide higher catch rates and simplify management.
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- Angling regulations are to be enacted to minimize catch and release impacts.
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- Management priorities should be identified and implemented to maintain stock abundance in the "Routine Management Status". When the stock status of wild steelhead populations are declining towards or have declined to "Conservation Concern" levels or lower, management prescriptions designed to recover stocks to the "Routine Management Status" should be developed.
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- Management prescriptions should focus first and foremost on restoring stock abundance through improved stock management and/or habitat protection, habitat improvement that mimics natural habitat or enrichment of natural habitat.
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- Where the requirement for a Recovery Plan (under the Accord for the Protection of Species at Risk or the Species at Risk Act) is identified for a steelhead stock or stock group, then it will be undertaken according to provincial policy and procedures. The use of conservation fish culture designed to conserve within stock genetic diversity is an acceptable short-term option (one generation) if it is part of a provincially approved recovery plan.
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- Adult brood stock, smolts or parr may not be taken from wild steelhead streams for hatchery augmentation on other systems unless:
 1. a risk assessment has been prepared by the proponent and approved by the Anadromous Fisheries Committee as an exception to the general practice of not transplanting steelhead between watersheds;
 2. the status of the wild donor stock is in the Routine Management Status and
 3. approval is obtained from the Federal/Provincial Introductions and Transfer Committee.
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- Non-government partners and public involvement groups should be encouraged to undertake projects which promote wild stock recovery through, habitat protection and restoration or enrichment of natural habitat.

"Hatchery-augmented" streams

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All hatchery-augmented fish must be marked with at least an adipose fin clip and regulations enacted that will limit catch and release impacts on wild steelhead as much as possible, and only permit retention by angling on marked hatchery-augmented fish.

- Hatchery programs must be evaluated annually to confirm predicted program objectives and outcomes are being achieved for the augmented and neighbouring streams. Hatchery programs, which are not meeting predicted objectives and outcomes, will be adjusted or discontinued.

- Hatchery augmentation, must follow current best practices for steelhead culture as established by the Freshwater Fisheries Society of BC and the Ministry of Land, Water and Air Protection.

a) Where an indigenous population is extant in a stream that has been or will be hatchery augmented to create a retention fishery for marked steelhead:

- A management prescription must be prepared that is designed to maintain indigenous populations and their habitats.

- The management prescription must consider the consequences identified during the classification process and establish practices to minimize any potentially negative impacts on indigenous steelhead stocks.

- This risk will be considered acceptable where there are or expected to be significant angling benefits and the augmentation program is not expected to impact the overall health of wild-indigenous steelhead populations.

- Management priorities should be identified and implemented to maintain the abundance of unmarked wild –indigenous steelhead populations in the “Routine Management status”. When the stock status of wild steelhead populations are declining towards or have declined to “Conservation Concern” levels or lower, management prescriptions designed to recover stocks to the "Routine Management Status" should be developed.

- Management prescriptions should focus first and foremost on restoring stock abundance through improved management and/or habitat protection, habitat improvement that mimics natural habitat or enrichment of natural habitat.

- Unmarked steelhead adults from the same stream should be used for brood stock when sufficient wild stock are available and comprise the majority of annual spawning escapements.

- Hatchery steelhead releases must be at locations and times where they will have minimum impact on wild fish.

b) Where a wild population of steelhead has never existed, been extirpated, or is not sufficiently abundant to meet the accepted definition of a viable stock, a new population of steelhead may be considered for introduction through hatchery augmentation to create a steelhead angling opportunity.

- A management prescription must be prepared that considers consequences identified during the classification process and establishes practices to minimize any potentially negative impacts.

- Marked steelhead brood stock from the closest available stream, which is part of the same stock grouping, is the preferred source for hatchery augmentation. Progeny from captive brood programs may be used for this purpose.

Management prescriptions will be developed regionally and reviewed technically by the Anadromous Fisheries Committee. They will be submitted to the Environmental Stewardship Division Management Committee (DMC) for a final decision. A structured decision making process will be followed where required.

The Ministry will use measurable criteria, standards and guidelines, including monitoring and evaluation requirements, to implement the Steelhead Stream Classification Policy and Procedure. The Steelhead Stream Classification Policy and Procedure will be reviewed within five years by the DMC and modified where appropriate based on experience and changing conditions.

1 Conservation Fish Culture is a specialized and experimental form of hatchery intervention designed to prevent the extinction of a population or species while the root causes of population decline are ascertained and addressed. The primary focus of conservation fish culture is to protect the natural genetic integrity of the population. Such a program requires a carefully designed breeding plan and release strategy to mimic what would happen in the wild. These programs are planned to be “temporary”, usually lasting for one generation. A conservation fish culture program differs significantly from the traditional production hatchery program where the main objective is to provide for angling opportunities.